TARDEC

Implementation of ERDC HEP Geo-material Model in CTH and Application to Buried Explosives Simulations

Dr. Richard Weed and Christopher Moore
Center for Advanced Vehicular Systems
Mississippi State University

Dr. Ravi Thyagarajan
Army Tank Automotive Research, Development, and Engineering Center

82nd Shock and Vibration Symposium
Baltimore, MD
November 2, 2011

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
03 NOV 2011	**Briefing Charts**	**03-11-2011 to 03-11-2011**

4. TITLE AND SUBTITLE
IMPLEMENTATION OF THE ERDC HEP GEO-MATERIAL MODEL IN THE CTH HYDROCODE AND APPLICATION BURIED EXPLOSIVES SIMULATIONS

5a. CONTRACT NUMBER
w56hzv-08-c-0236

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Ravi Thyagarajan; Richard Weed; Christoper Moore

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Center for Advanced Vehicular Systems,Mississippi State University,Mississippi State,Ms,39759

8. PERFORMING ORGANIZATION REPORT NUMBER
; #22403

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)
TARDEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
#22403

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
presented to 82nd shock and vibration symposium, Baltimore, MD november 2, 2011

14. ABSTRACT
Work performed under TARDEC/MSU Simulation Based Reliability and Safety (SimBRS) Work Directive 37 ? CTH Analysis Support and Code Enhancement TARDEC identified implementation of ERDC Hybrid Elastic-Plastic Geo-material model in CTH as a priority task Standard model at ERDC for soils (also rocks and concrete) Large library of HEP model fits for different soil types Proven to provide accurate model for buried explosions in soils in Lagrangian codes (EPIC, PRONTO3D, SABER) Current CTH implementation first successful one for Eulerian or ALE codes

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**24**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Background

- Work performed under TARDEC/MSU Simulation Based Reliability and Safety (SimBRS) Work Directive 37 – CTH Analysis Support and Code Enhancement
- TARDEC identified implementation of ERDC Hybrid Elastic-Plastic Geo-material model in CTH as a priority task
  - Standard model at ERDC for soils (also rocks and concrete)
  - Large library of HEP model fits for different soil types
  - Proven to provide accurate model for buried explosions in soils in Lagrangian codes (EPIC, PRONTO3D, SABER)
- Current CTH implementation first successful one for Eulerian or ALE codes

MISSISSIPPI STATE UNIVERSITY

TARDEC

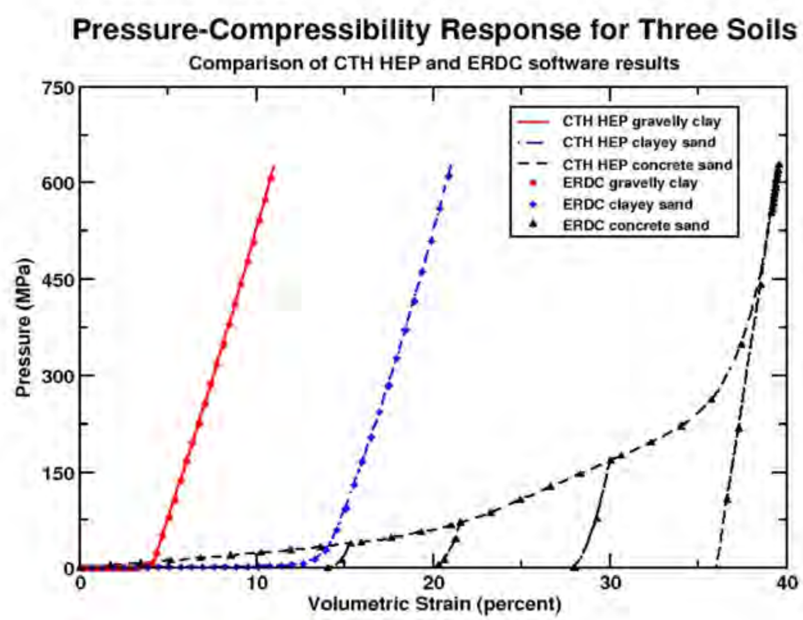
HEP Model Basics

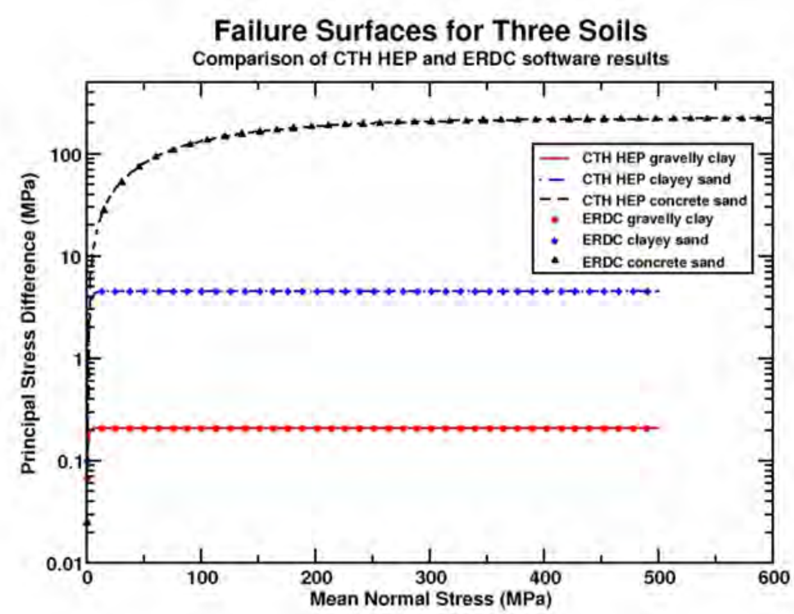
- HEP EOS model is a modified Tillotson equation
  - Hydrostatic term a function of compression (vol. strain)
  - Energy term function of density and internal energy
  - Referenced to gage pressure with energy assumed to be zero at reference condition
  - EOS allows hysteritic loading and unloading up to void crush out
    - Various forms of loading and unloading curves supported
  - Supports high pressure regions beyond void crush plus solid-solid and fluid phase transitions
- SHEP constitutive model consists of pressure dependent exponential yield function and shear modulus with support for different loading and unloading Poisson ratios
- Current implementation requires max. compression at previous time step as a "history" variable

MISSISSIPPI STATE UNIVERSITY

TARDEC

Typical HEP Hydrostat and Yield Surface





Hydrostat and yield surface for three HEP library soils

CAVS

SimBRS

CTH Implementation Overview

- Current implementation is in CTH V9
- Simple HEP (SHEP) variant of HEP model
- New Fortran 2003 code written to replace existing F77 code
- MIG guidelines followed for EOS implementation
  - JH ceramic models used as examples
- Strength model implemented as a "Traditional" CTH elastic-plastic model
- Implementation issues
  - Advection of maximum compression "history variable"
  - Energy shift needed due to gage pressure reference
  - Energy-temperature relationship needed to satisfy CTH requirements for two EOS routines - $(P,T,Cs)=P(\rho,e)$ and $(P,e,Cs)=P(\rho,T)$
    - Cv value based on mass fraction weighting of dry material and water Cv values

Testing and Validation

TARDEC

- Unit testing used to debug software outside of CTH
- CTH PRDEF runs for three test soils
- 2D witness plate calculations used to verify CTH EOS implementation
  - Gerry Kerley cases run and compared with Kerley's SESAME soil fits*
  - Comparisons with Dave Littlefield's EPIC and CTH results from last years meeting**
- Comparison with ERDC Impulse Measurement Device (IMD) experiments and EPIC calculations***
- 3D simulations of DRDC plate experiment and comparison with TARDEC LS-DYNA ALE simulations****

* Kerley, ARL-CR-461, KTS02-3, KTS05-3

** Littlefield, 81st Shock and Vibration Symposium presentation

*** Moral et al, ERDC GSL-TR-10-27 and Ehrgott, ERDC GSL-TR-10-7

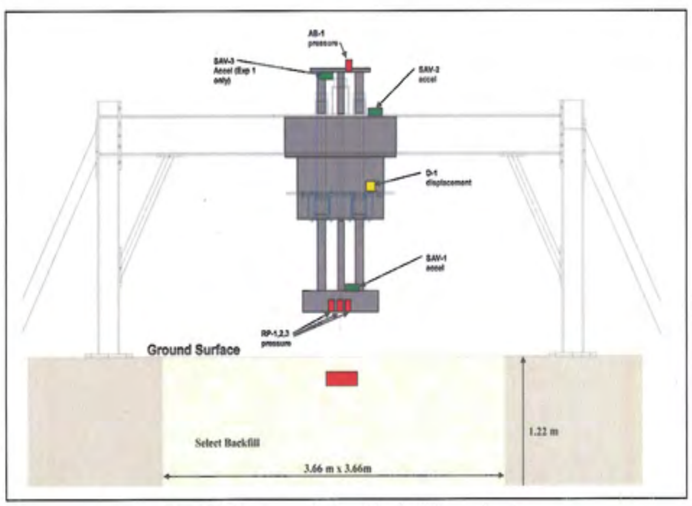
**** Williams et al, 7th International LS-DYNA Users Conference paper

ERDC IMD CTH HEP Tests

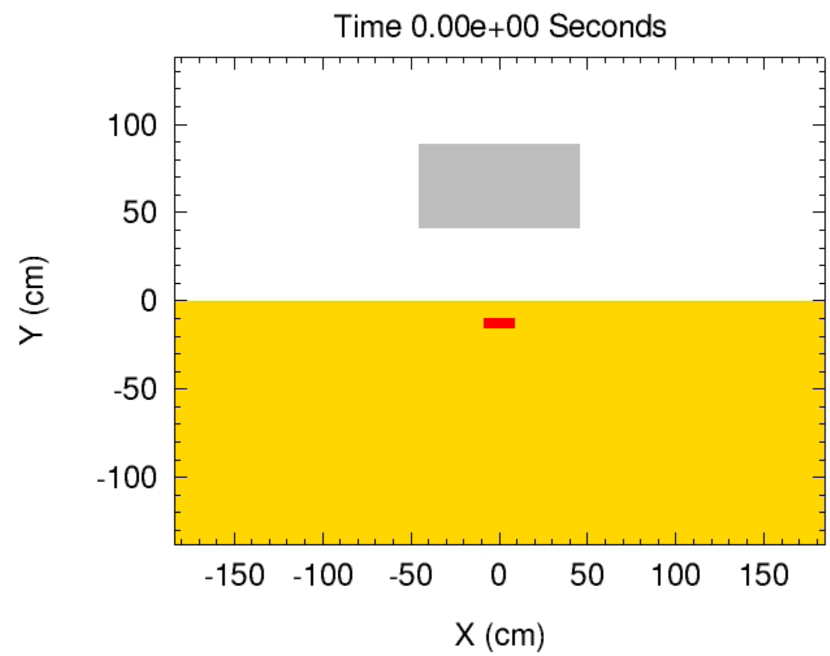
TARDEC

- CTH HEP impulse and crater dimension results correlated with EPIC and experiment for IMD three test soils
  - CTH simulations run in 2D cylindrical coordinates with 1cm and 0.5 cm mesh spacing. EPIC results are for a 0.6 cm and 0.3 cm mesh spacing
  - Results shown are for 4 inch DOB using a 5lb cylinder of C4

ERDC IMD Facility



CTH Initial Configuration



IMD TEST SOILS

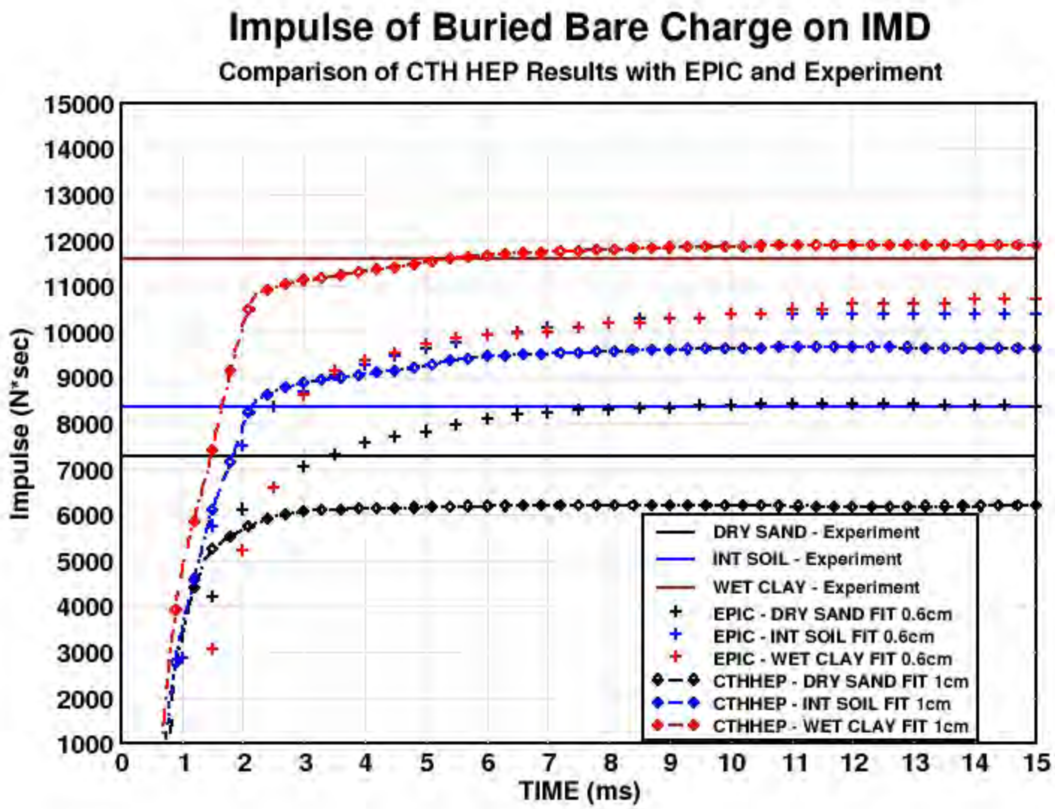
- ERDC fit HEP model to three test soils used in IMD experiments

Material Description	ERDC Material Classification	Soil Classification	Air Voids, %	Wet Density, Mg/M^3	Dry Density, Mg/M^3	Water Content, %
Clay	WET CLAY	CL	3.4	1.97	1.59	24.0
Silty Sand	INT SOIL	SC	10.9	2.01	1.84	12.7
Dry Sand	DRY SAND	SP	29.8	1.77	1.70	3.8

CTH HEP Impulse Correlations

TARDEC

Experiment values are maximum impulse based on peak initial velocity measured by high speed cameras



- Wet clay and Intermediate soil correlations are as good as or better than EPIC for 1cm CTH mesh. EPIC results improve when mesh is reduced to 3mm but are slightly better than CTH for DRY SAND fit
- Dry sand results indicate CTH HEP model is over-predicting material strength. Correlation improves if shear modulus is reduced

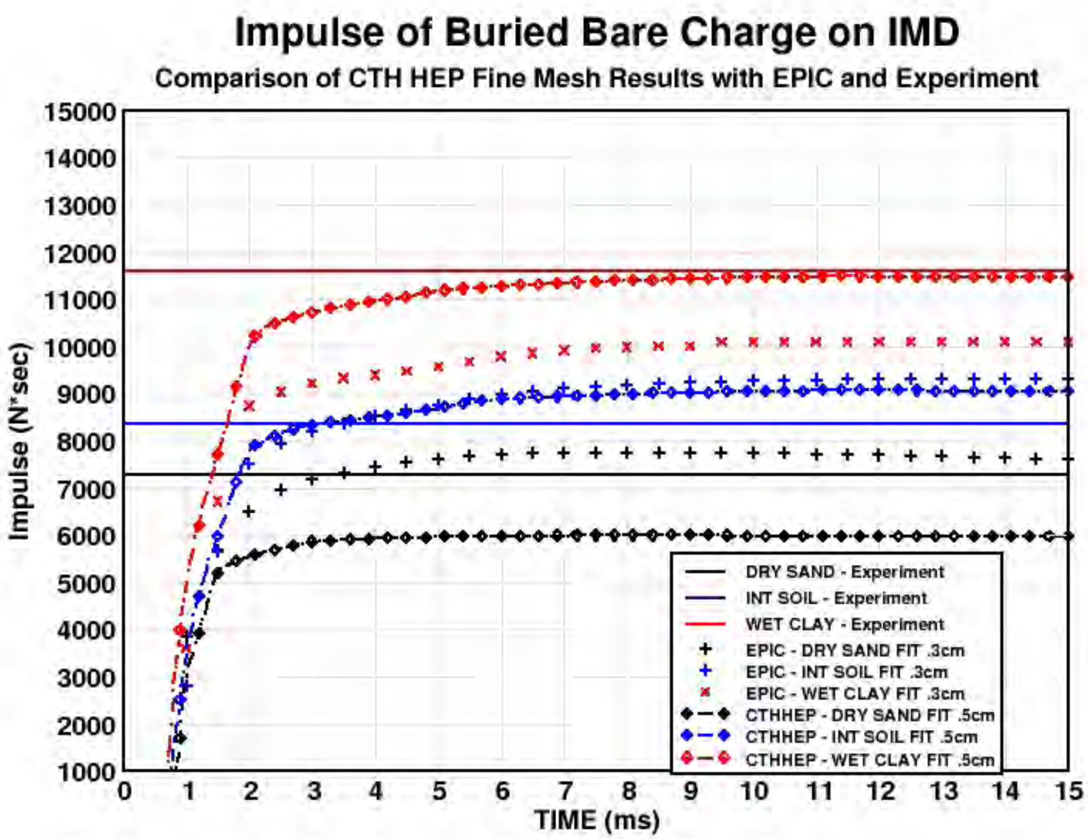
MISSISSIPPI STATE UNIVERSITY

TARDEC

Effect of Mesh Spacing on CTH HEP Impulse

CTH mesh spacing halved to 0.5 CM. EPIC mesh was halved to 0.3 cm

Default CTH PFRAC model used with PFRAC for soil of -1.E6



-Max values for all three soils move down with INT SOIL effected most
-DRY SAND still under predicts experiment indicating need for a better model for soil fracture that weakens shear strength

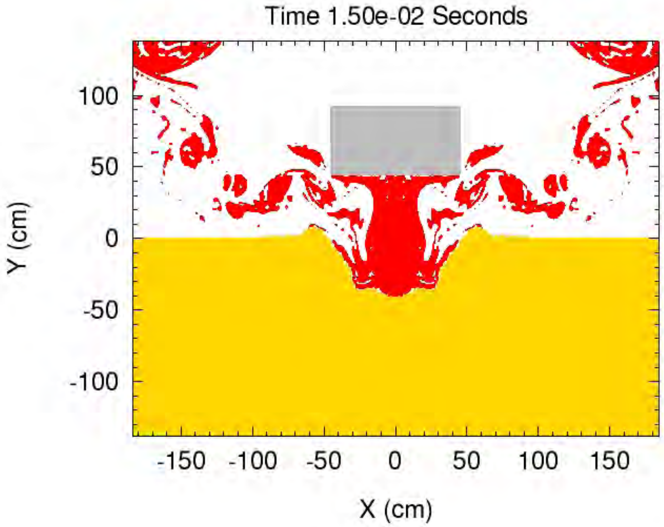
CAVS

UNCLASSIFIED: Distribution A. Approved for public release

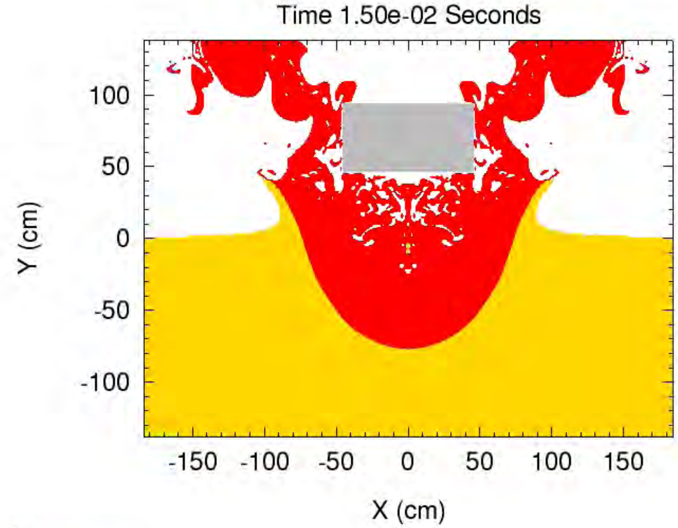
SimBRS

Comparison of computed craters at 15 ms (1CM – PFRAC)

TARDEC



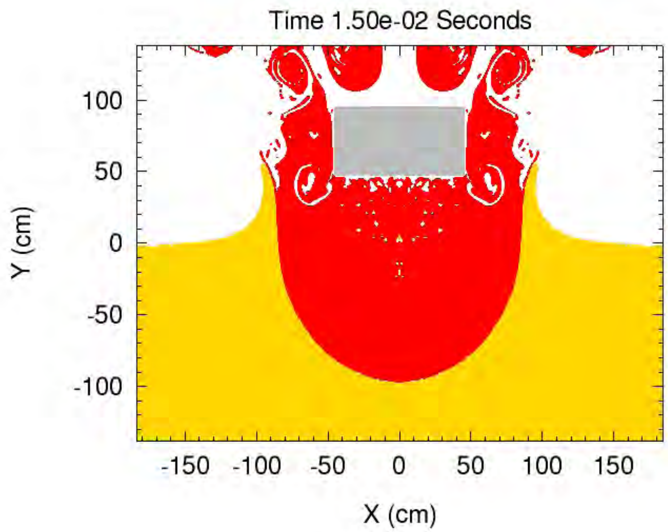
DRY SAND



INTERMEDIATE SOIL

CRATER DEPTH (cm)

Soil	Exp.	CTH HEP
Dry Sand	39.	39.
Int. Soil	57.	78.
Wet Clay	106.	98.



WET CLAY

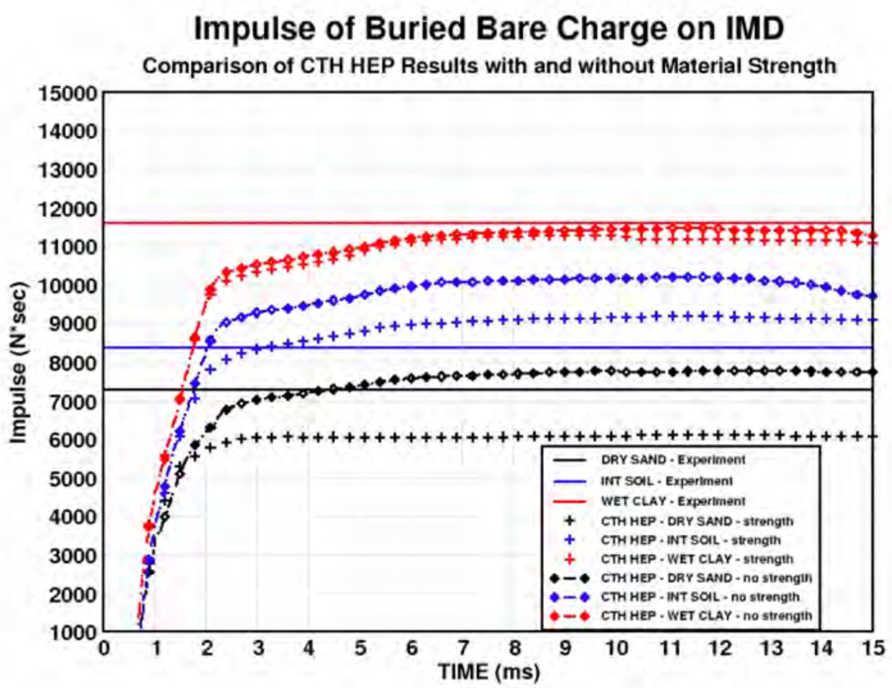
Gold – soil
Red - C4 det. products
White – Air or void

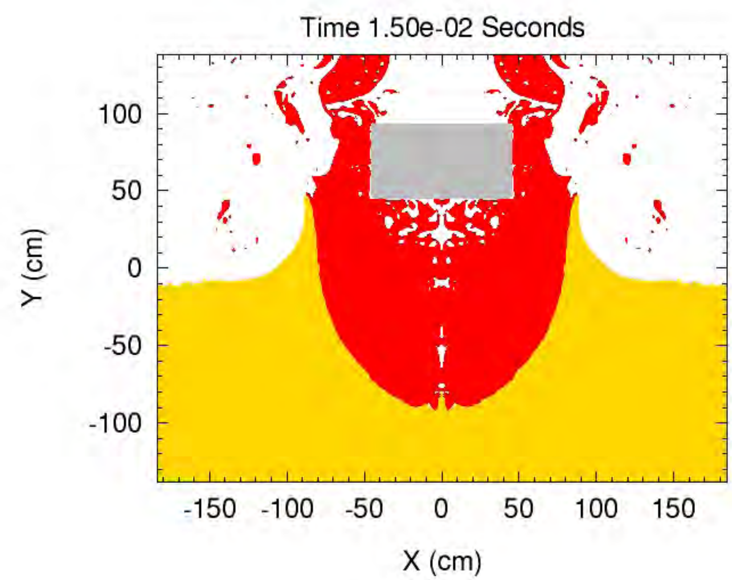
MISSISSIPPI STATE UNIVERSITY

TARDEC

Effect of Material Strength on Impulse and Crater Geometry

1cm mesh with PFRAC=-1E6





DRY SAND without strength

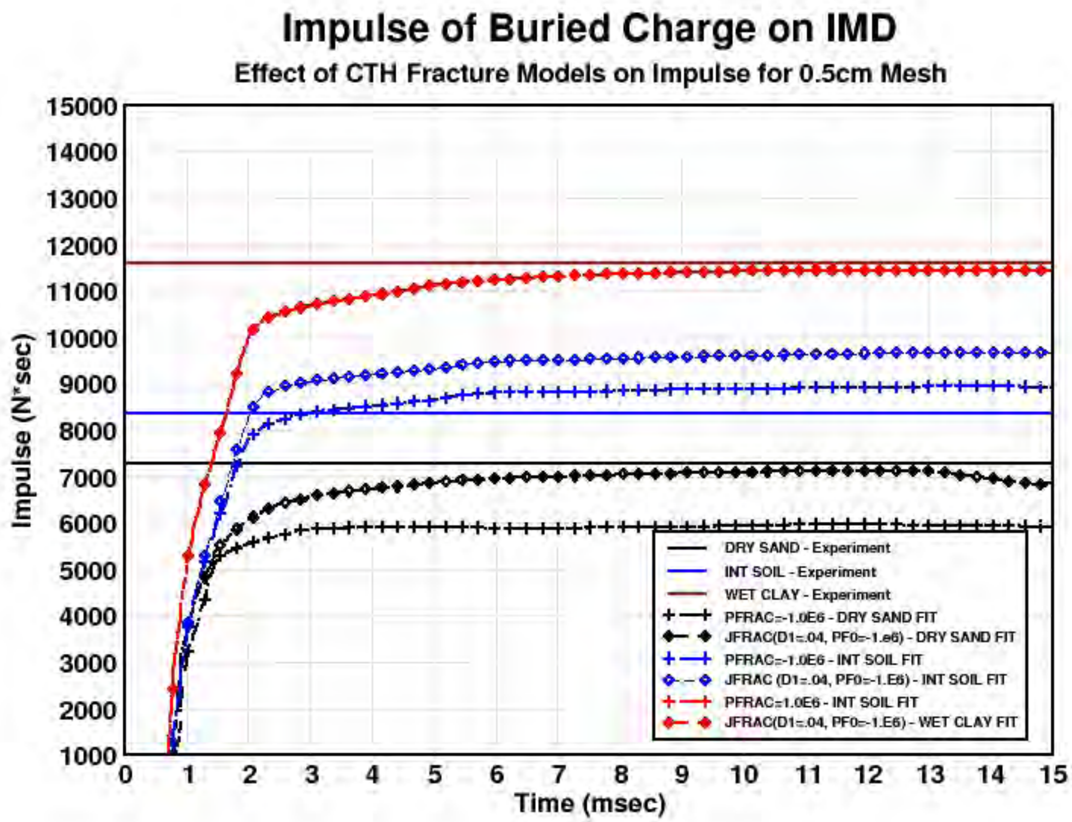
- DRY SAND results indicate material strength not being correctly modified for material fracture
- Wetter materials show less effect on impulse
- Wrong crater dimensions without strength

CAVS

SimCAVS

Using JC Fracture Model with HEP

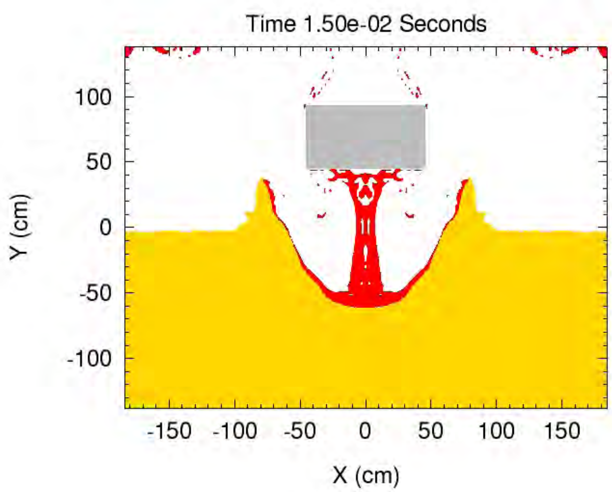
TARDEC



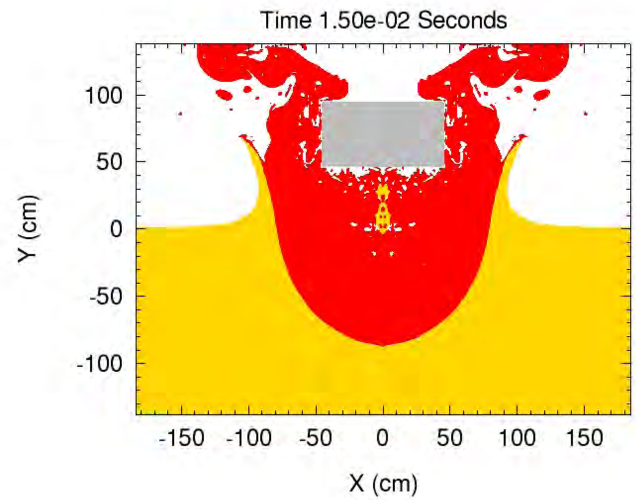
- EPIC HEP model requires a failure equivalent strain as input and bypasses HEP model when it is exceeded
- Similar effect modeled in CTH using JC fracture model with D1=4% and PF0=-1E6

Comparison of computed craters at 15 ms using JC FRAC

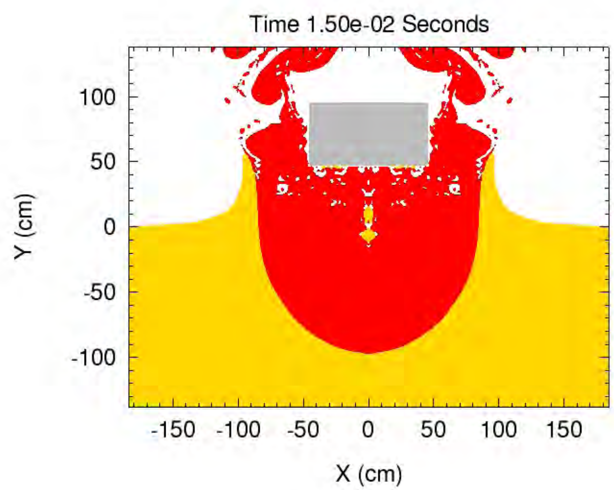
TARDEC



DRY SAND



INTERMEDIATE SOIL



WET CLAY

Using JC FRAC effects DRY_SAND crater depth the most.

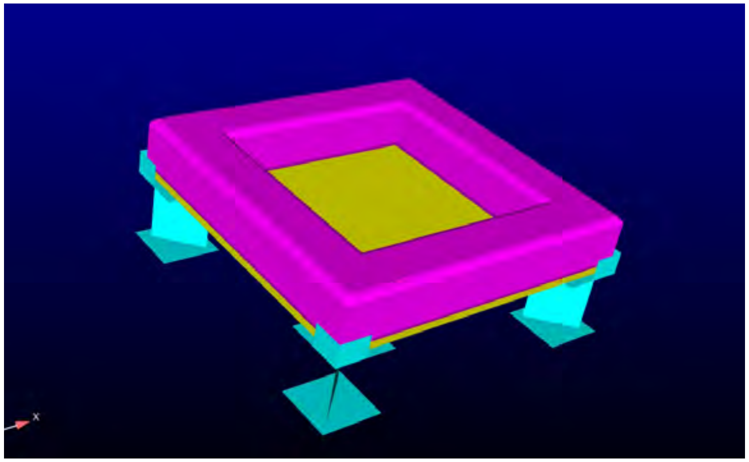
Gold – soil
Red - C4 det. products
White – Air or void

DRDC Plate Experiment Simulations

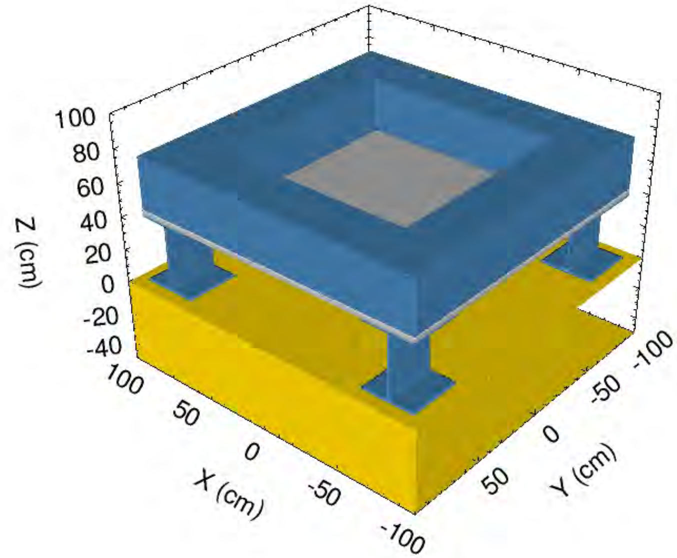
- At Ravi's suggestion performed 3D sims of DRDC plate experiment
  - Ravi provided LS-DYNA ALE and LOAD_BLAST models
  - Shell element geometry converted to solids for CTH DIATOM input
  - Used 5083-AL target plate (RHA plate also tested in experiments)
  - HEP IMD_DRY_SAND used for soil model in CTH runs
  - LS-DYNA used ATC soil fit for LS-DYNA MAT_ ELASTIC_PLASTIC_HYDRO_SPALL with density correction
  - Final CTH runs used TARDEC JWL inputs for C4 and Johnson-Cook Strength inputs
    - TARDEC JC fracture model inputs for 5083 plate changed due to problems seen in both LS-DYNA and CTH runs

CTH and LS-DYNA DRDC Plate Models

- 6kg C4 at 5.08 cm DOB
- 31.75 mm thick AL5083-H131 target plate
- 10 metric tons of mass added to top of support frame (not shown)
- CTH mesh used quarter symmetry with 0.5cm mesh spacing in all directions up to 100 cm from symmetry planes. Mesh stretching was used to locate outer boundaries away from geometry. Resulting CTH mesh has 38,330,568 (282x282x482) cells

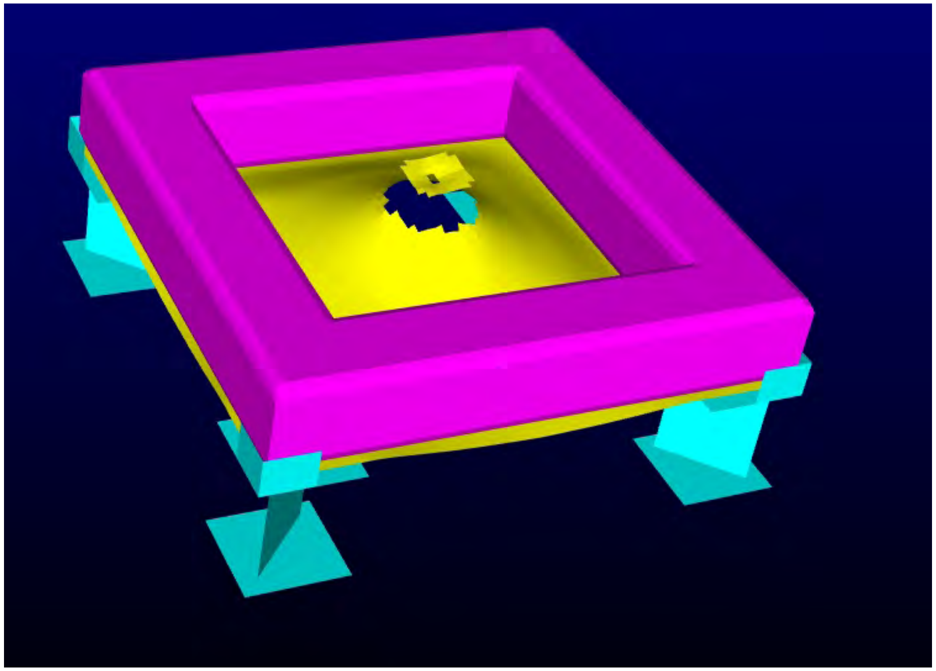


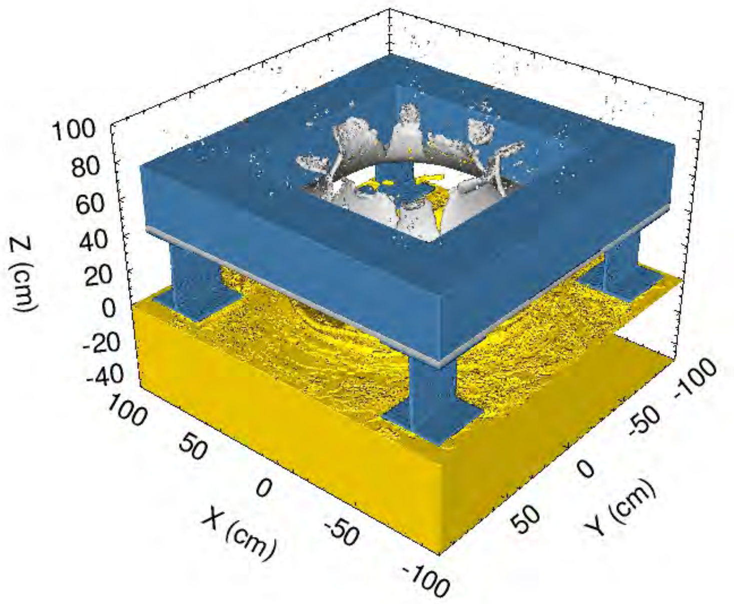
LS-DYNA Model



CTH Model

LS-DYNA and CTH Results at 6ms with Default TARDEC JC inputs



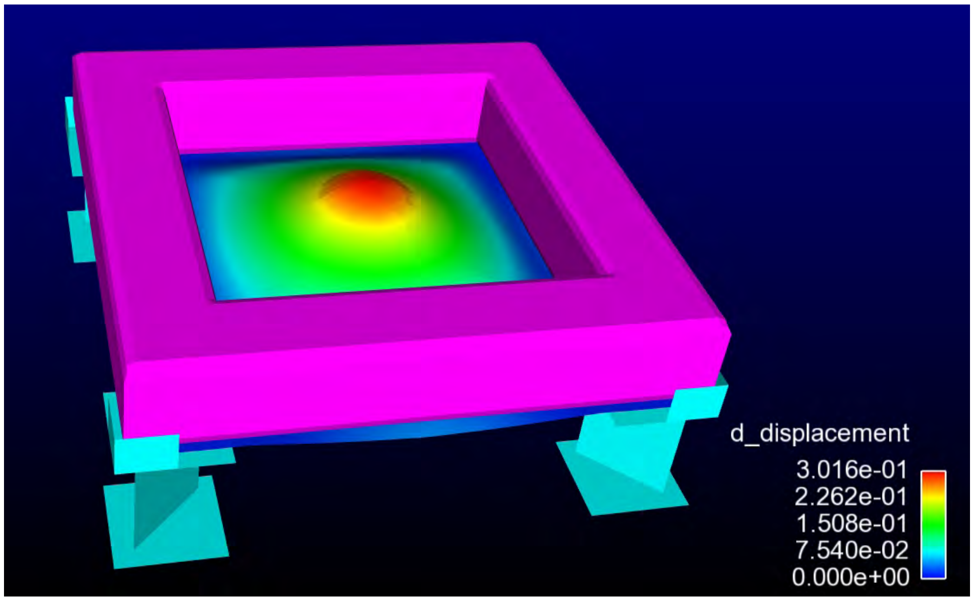


LS-DYNA ALE

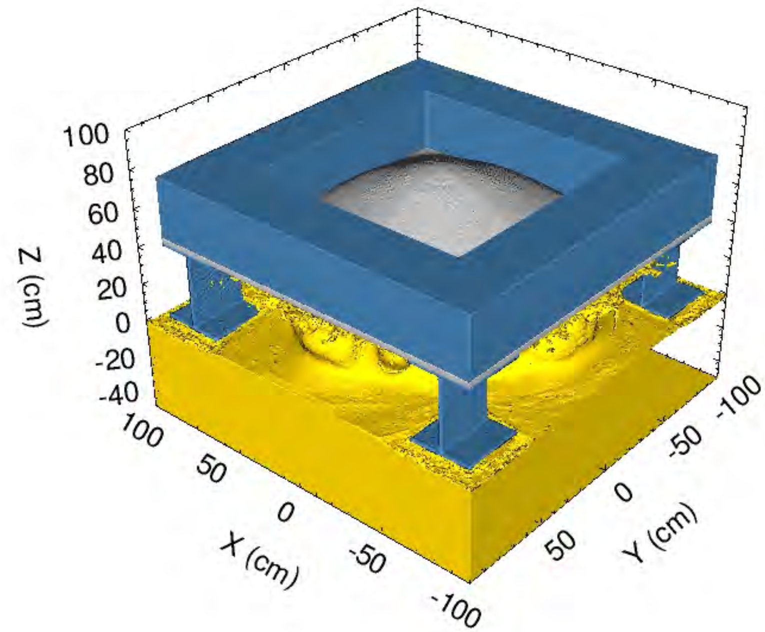
CTH HEP

- Results using Default TARDEC JC fracture model and strength model inputs
- CTH HEP DRY SAND soil model with PFRAC=1.e-6 used for CTH sims
- Fracture not seen in experiment for 5083AL plate
- Numerical experiments showed default JC fracture model inputs lead to fracture

LS-DYNA and CTH Results with modified JFRAC inputs at 6ms



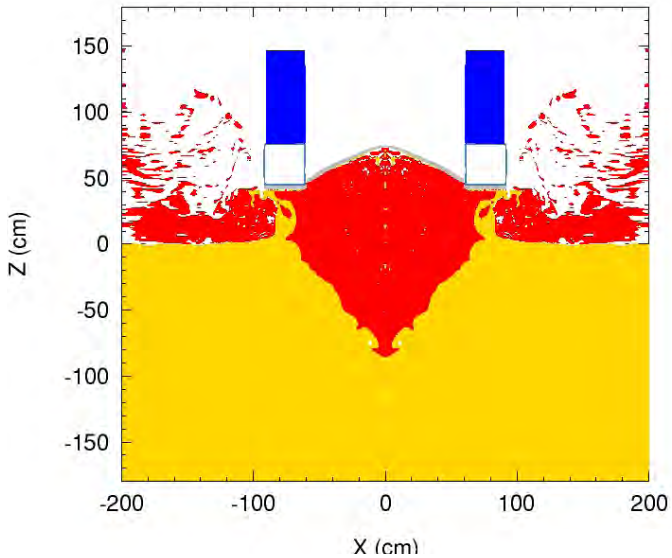
LS-DYNA ALE

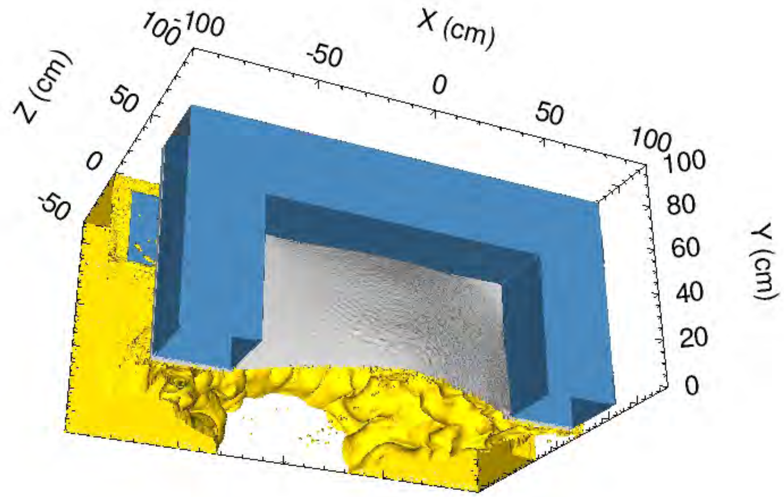


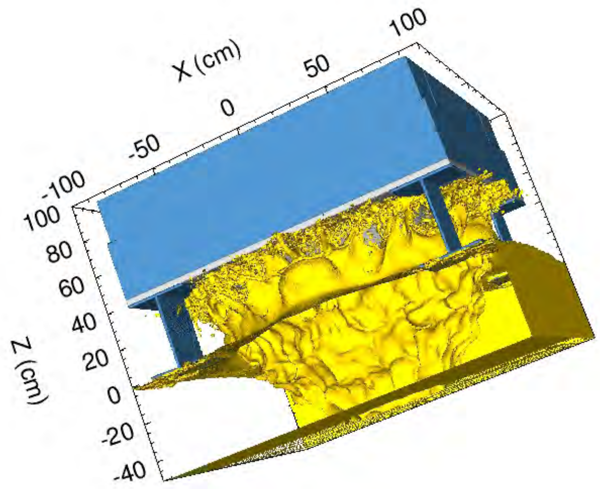
CTH HEP

- JC fracture inputs changed to D1=1.5, D2-D5=0., PF0=4.28 GPa
- CTH runs used IMD DRY SAND model with JC fracture inputs from IMD tests
- LS-DYNA C4 JWL and Johnson-Cook strength inputs used in CTH runs
- Results indicate that TARDEC JC fracture model inputs need to be re-evaluated

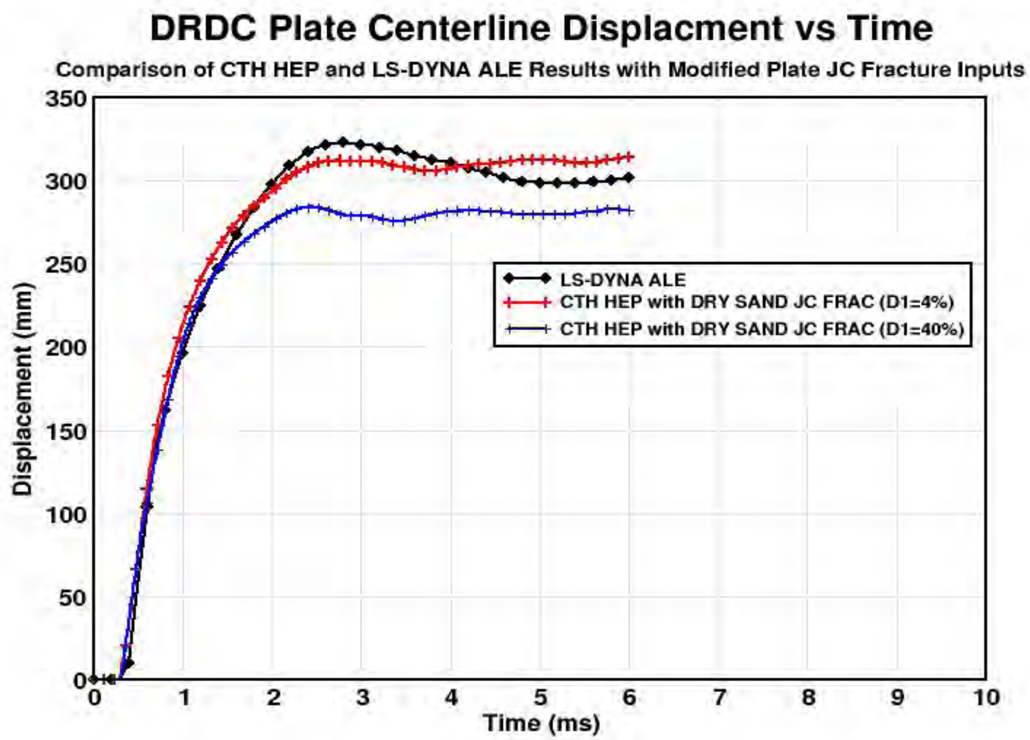
CTH Results for Modified JC Fracture Inputs (6ms)







LS-DYNA ALE and CTH Centerline Displacement

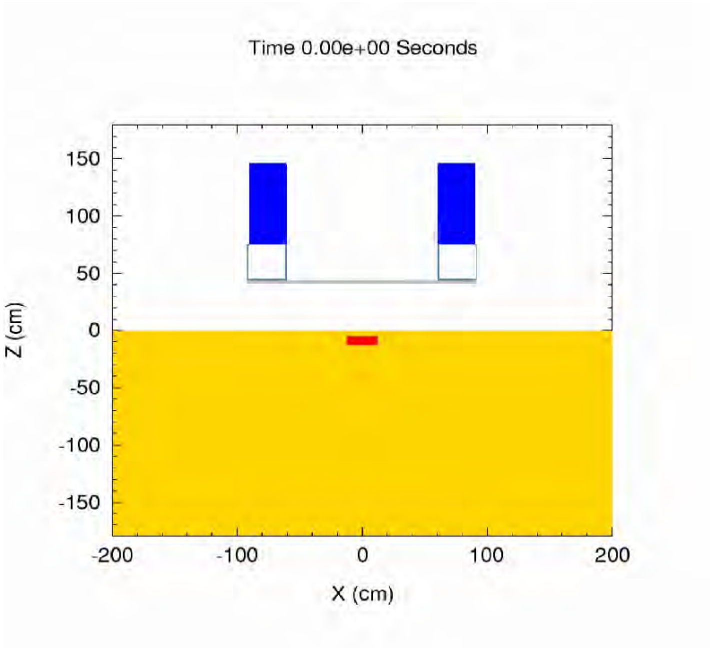


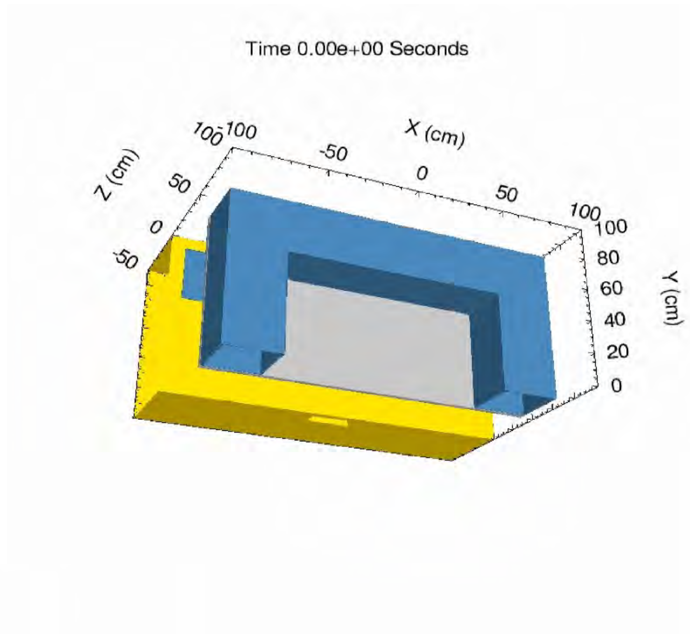
- Experiment showed final displacement along centerline of 300 mm
- CTH results with JC fracture for soils again shows importance of material strength for dryer (stronger) soils.

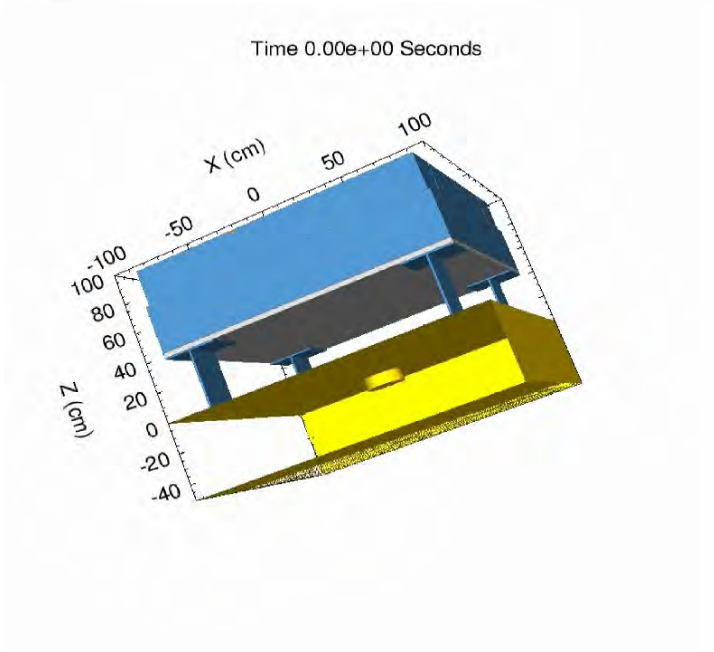
MISSISSIPPI STATE UNIVERSITY

DRDC CTH Animations

TARDEC







Modified JC fracture inputs

CAVS

UNCLASSIFIED: Distribution A. Approved for public release

SimBRS

Summary

- ERDC HEP model successfully implemented in CTH V9
  - Validated with 2D witness plate simulations and ERDC IMD results
  - Yields good to excellent correlation with EPIC and experiment for impulse and crater geometry
  - Using JC fracture model improves correlation for DRY SAND
  - More work needed on strength model
- 3D simulations of DRDC plate experiment for 5083 AL plate underway
  - Default TARDEC JC fracture inputs leads to plate fracture not seen in experiment for both LS-DYNA ALE and CTH
  - Modifying JC fracture model inputs for target plate produces more realistic results
  - Runs underway to quantify effects of soil model on plate response

Future Plans

- Investigate better methods for “fracturing” soil for dryer materials
- Simulate IMD Side on Pressure experiments
- Continue validation runs with DRDC plate
  - Validate with Littlefield’s one-way CTH-LS-DYNA coupling procedure
- Implement model into CTH V10
- Install code at TARDEC and ERDC DSRC

Acknowledgements

This material is based on work supported by the U.S. Army TACOM Life Cycle Command under Contract No. W56HZV-08-C-0236, through a subcontract with Mississippi State University, and was performed for the Simulation Based Reliability and Safety (SimBRS) research program. Any opinions, finding and conclusions or recommendations in this material are those of the author(s) and do not necessarily reflect the views of the U.S. Army TACOM Life Cycle Command

The authors also would like to thank Dr's Steve Akers, Ray Moral and Kent Danielson (ERDC/GSL) and Prof. Dave Littlefield (UAB) for providing documentation on the HEP model, HEP model fit data, EPIC correlation data, and advice on implementing the model.